PHYSICAL AND OPTICAL CHARACTERISTICS OF THIN LAYERS

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LONG-TERM GOALS

The long-term goal of this project is to be able to predict radiative transfer in natural waters via the inherent optical properties given the biogeochemical nature of the particles and dissolved materials and the physical forcing applied to the water column. Conversely we want to be able to determine the inherent optical properties and the nature of the particulate and dissolved materials and their space-time structure from upwelling radiance spectra.

SCIENTIFIC OBJECTIVES

The scientific objectives of this effort are: 1) To experimentally determine the forcing and mixing conditions that characterize thin layers and their concomitant Inherent and Apparent Optical Properties (IOP and AOP) ; 2) To experimentally and numerically test the backscattering-independent algorithm (Barnard et al.,1999a) to obtain the absorption coefficient from the upwelling radiance spectrum; and 3) To experimentally test our remote sensing model of fronts and internal waves (Zaneveld et al., 1998).

APPROACH

Our approach is to first develop the theoretical and experimental tools necessary to achieve the objectives. A model relating the dependence of the upwelling radiance spectrum on the vertical structure of the IOP as related to the physical structure (i.e. thin layers, fronts, and internal waves) was developed by Zaneveld and Pegau (1998). Numerical models relating the reflectance to thin layer characteristics have been developed (Petrenko et al., 1998). Models relating the IOP globally and to the remotely sensed reflectance have been developed by Barnard, Zaneveld, and Pegau (Barnard 1998, 1999) as well. These models provide the hypotheses to be tested during the field program. Instrumentation and calibration procedures have been and continue to be developed in order to measure the appropriate IOP and AOP accurately (Zaneveld et al. 1992, 1994, Pegau et al. 1993, 1995, 1996 etc.)

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Zaneveld, Barnard and Boss participated in two field experiments during 1998. Our approach was to measure spectral absorption and attenuation for dissolved and particulate materials and to measure the downwelling irradiance and upwelling radiance spectra as a function of depth, location within the Sound, tidal stage etc. This work was carried out in conjunction with other researchers, who, during the first experiment, measured the same parameters in addition to biogeochemical parameters from a barge moored within the Sound. Aircraft overflights using a spectral radiometer were carried out by the Naval Research Lab. (Dr. Curt Davis) during the second experiment.

WORK COMPLETED

We analyzed the global relationships between inherent optical properties using data from eight previous cruises. This work was published in the Journal of Geophysical Research (Barnard et al., 1998).

We developed an inversion method to obtain the absorption coefficient from the remotely sensed reflectance spectrum and used it to demonstrate closure between in situ IOP and AOP measurements. This work has been published in Applied Optics (Barnard et al., 1999a).

The in-situ data has been analyzed to determine the effects of vertical structure on the remotely sensed reflectance. This work was presented at the 1999 ASLO meeting (Barnard et al., 1999b).

We completed processing the data from two experiments conducted in East Sound during 1998. The data is available on CD-ROM or from our anonymous ftp site (photon.oce.orst.edu). The data has been provided to other participants in this program.

High-frequency hydrographic, spectral absorption, attenuation and fluorescence profiles were obtained from two platforms, a mooring and a ship, at East Sound, WA, as part of the Thin Layer Experiment. The spectral absorption and fluorescence of the total and dissolved components were measured so that the contribution by particulate matter could be computed. The spatial scales governing the distribution hydrographic and bio-optical properties are computed in order to elucidate the degree of coherence between them. We then examined the respective contribution of these scales to the observed optical variability. The temporal variability in optical parameters on isopycnals was calculated in order to provide the rates of processes affecting their distribution. The results have been interpreted and contrasted with processes that are known to contribute and control the distribution of physical, biological, and optical variability (Boss et al., 1999).

RESULTS

We demonstrated that on a global scale the relationship between $a(\lambda)$ and $a(488)$ for particles and CDOM, but also for total absorption can be statistically described by a straight line. This does not imply that the shape of the spectrum is constant. That is only the case if the intercept is zero. These relationships show that excellent (about 0.005 m^{-1}) inter-cruise calibration exists (Barnard et al. 1998a).

Closure for in situ observations of the IOP and AOP was demonstrated using a backscattering independent algorithm that relates the reflectance at three wavelengths to the absorption coefficient at three wavelengths (Barnard et al., 1999a). In this paper we show that a ratio of absorption coefficients

has a linear relationship to a ratio of reflectances (figure 1) and that the absorption coefficient at 488 nm can be retrieved when the reflectances at three wavelengths are known (figure 2).

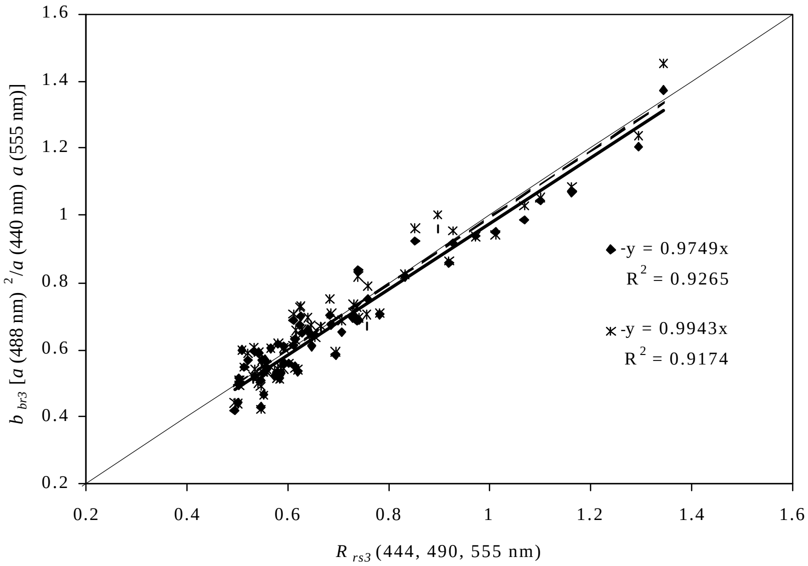

Figure 1. Triple ratio of the remote sensing reflectance at 443, 490, and 555 nm determined from in situ radiometer measurements versus the triple ratio of the absorption coefficient times the backscattering triple ratio at 440, 488 and 555 nm determined from in situ ac-9 measurements. The filled diamonds are for the constant case, b_{br3}=1.0, and the asterisks are for the modeled backscattering varying b_{br3} case. The solid thick and dashed lines are the regressions for the constant and varying b_{br3} cases. Also plotted is the 1:1 line.

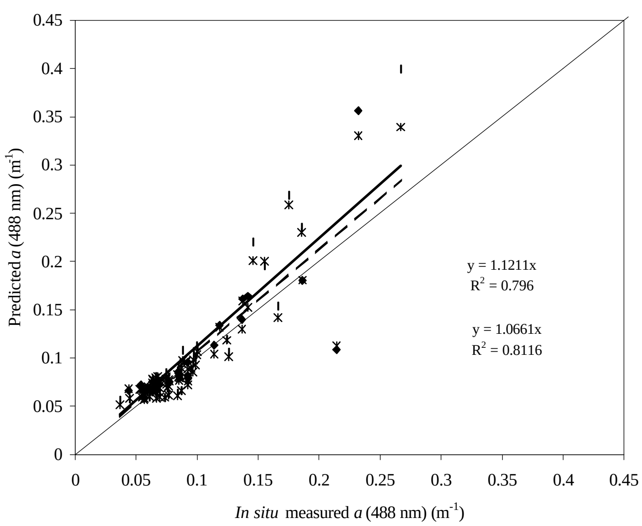

Figure 2 The in situ measured optically weighted absorption coefficient at 488 nm versus the predicted absorption coefficient at 488 nm based on the remote sensing reflectance triple ratio and the absorption relationships at 443 and 555 nm (see figure 3 and Eq. 14). The solid diamonds are for the constant b_{br3} (1.0) case, and the asterisks are for the varying b_{br3} case. The solid thick and dashed lines are the regressions for the constant and varying b_{br3} cases. Also plotted is the 1:1 line.

During the first East Sound cruise we preformed several along sound sections from which we observed how thin layers at the head of the basin are directly linked to much thicker layers towards the middle of the basin (Fig. 3). The shear causing the formation of these layers is provided by the along sound winds.

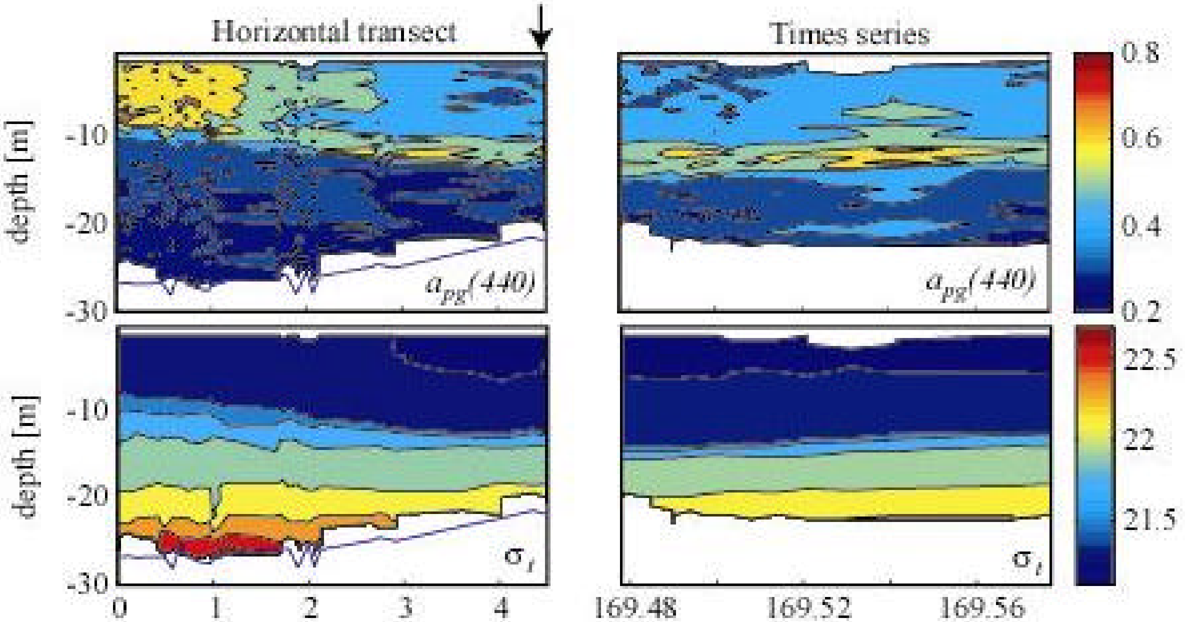

Figure 3. Absorption by particles and CDOM at 440nm and density as measured along East-Sound and during time series at the north end of the basin at the same time (the position is denoted by the arrow in the section). Note the band with high absorption values at ~12 m depth that connects to the region of high absorption towards the mouth of the sound and its association with the isopycnal at that depth. Data for the time series was provided by Dr. T. Cowles. The wind was blowing from the South (from left to right), ‘piling’ light waters in the basin end.

Medians of the variance spectra of the vertical distribution of optical and physical data (Fig. 4) reveals the differences between them especially over scales smaller than 5m. The physical variance cascades down to the dissipative scales in an inertial sub-range while variability in optical properties is much whiter. CDOM is the most conservative, while particulate properties (absorption and fluorescence) have much whiter spectra (CDOM variance below 2m is due to instrumental noise).

IMPACT/APPLICATIONS

There have been widespread applications of our ac-9 calibration procedures including the temperature dependence of absorption by pure water (Pegau et al. 1997). These procedures continue to be refined for the HiStar devices.

The theoretical work (Zaneveld and Pegau, 1998; Petrenko et al., 1998) will be used in inverting remotely sensed reflectance to obtain vertical structure of the IOP and so to infer physical structure.

Having demonstrated closure between IOP and AOP in situ (Barnard et al., 1999a), in situ observations of IOP combined with inversions show that IOP can be used to vicariously calibrate satellite radiance sensors. This is important as atmospheric corrections, especially near shore still are problematic.

The data from the Thin Layers Experiments is being shared with other researchers to examine the effect of physical forcing on the generation and maintenance of thin optical/biological layers. The data is also being used to examine algorithms for the inversion of remotely sensed radiance.

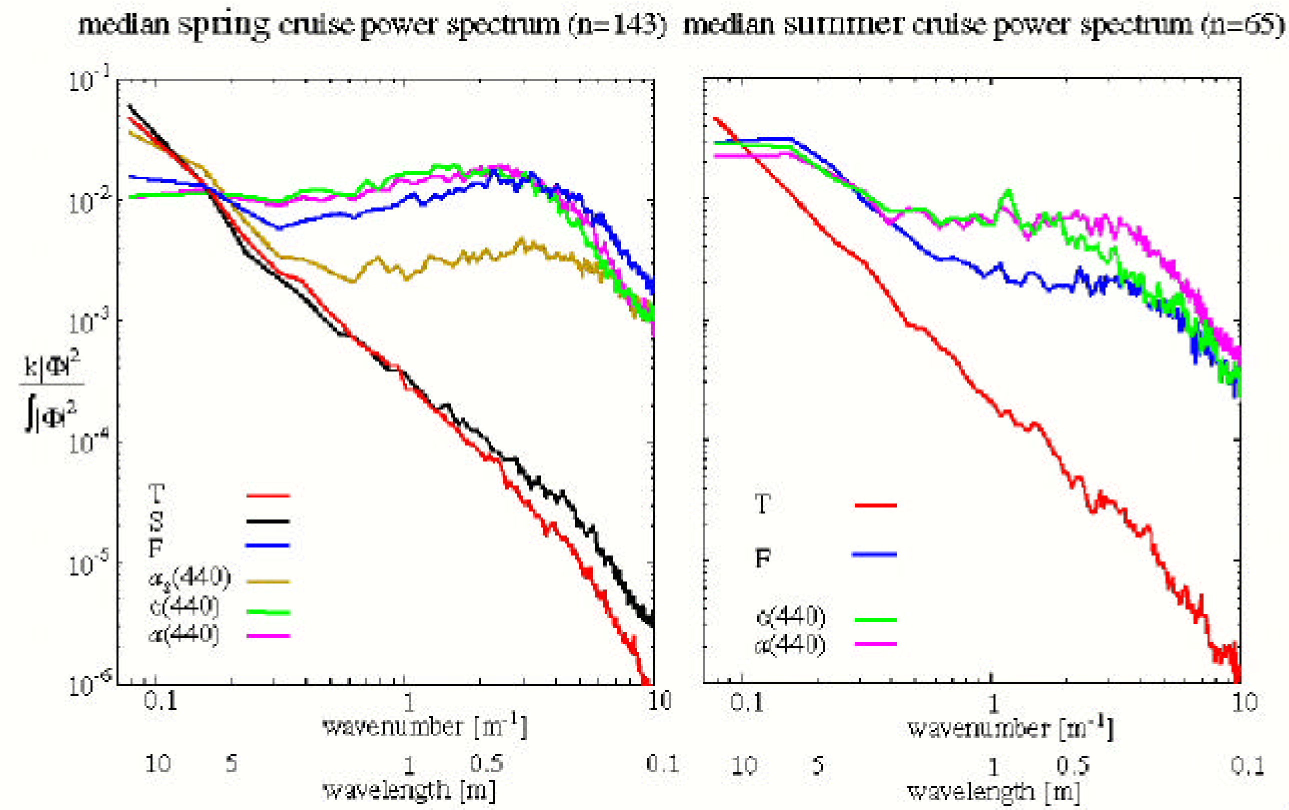

Figure 4. Median variance spectra of the vertical distribution of optical (absorption, attenuation and fluorescence) and physical (temperature and salinity) variables for the two sampling seasons. While

TRANSITIONS

Instrumentation and calibration procedures developed at O.S.U. or in cooperation are widely used for the accurate in situ observation of the spectral absorption, scattering and attenuation coefficients.

Theoretical efforts and analyses carried out using ONR core funding have led to follow-on studies by other researchers and are frequently cited.

We have cooperated frequently with the Naval Research Laboratory (Drs. C. Davis and A. Weidemann) in the measurement and interpretation of the IOP as related to remote sensing and dynamics (Bivens et al., 1999).

RELATED PROJECTS

Coastal Mixing and Optics- ONR: Analytical and numerical methods developed under the grant described here are used in the interpretation of data collected during CM&O.

SIMBIOS-NASA: The remote sensing algorithm and instrumentation techniques and calibration are used to interpret data collected under the SIMBIOS program.

SeaWiFS-NASA: This project co-sponsored the development of the inversion algorithm to obtain absorption from remotely sensed reflectance.

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